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RESEARCH ARTICLE

# Comparative analysis of phytolith spectra of steppe and forest phytocoenoses

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## Abstract

The primary research goal is to identify differences and diagnostic features of the phytolith spectra of the steppe and forest phytocoenoses. The paper presents the research results of recent soils from various communities. The authors employ the phytolith analysis method. The isolation of phytoliths from recent soils has been carried out with the help of the maceration method and from plants – the dry ashing method. The authors counted the phytoliths using the Olympus BX-51 light microscope. Additionally, the authors have compiled the spectra using the 2C software. The paper compares the phytolith spectra of plain and mountain steppe phytocoenoses. The comparison reveals that the considered plain communities are more similar in phytolith composition than the mountain ones. The following morphotypes are common for all spectra: low conical rondel particles and psilate ribbed particles. These are the forms that characterize steppe communities. Analysis of phytolith spectra of the mountain forest communities demonstrates that the presence of ribbed particles of psilate is common for all spectra. The common feature of all forest spectra is the presence of psilate symmetrical particles, polylobate trapeziforms, lanceolates (trichomes) with a massive base, and trapeziform bilobate ("Stipa-type") particles. In the spectra of all pine forests, there is a low content or complete absence of needle phytoliths. Diagnostic features of individual phytocoenoses have not been found. The most significant is the ratio of individual phytolith forms in the phytolith spectrum. The comparative analysis of phytolith spectra of the phytocoenoses in the south of western Siberia is carried out for the first time.

## Keywords

Phytolith analysis, phytoliths, phytocoenoses, steppes, pine forests

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## Introduction

Phytoliths (from Gr. *phyton* [plant] and *lithos* [stone]) are siliceous particles of an original form that form in plants. When plants die, the organic part decomposes, and the mineral compounds remain unchanged. As a result, phytoliths of different plants that make up phytocoenosis accumulate in the soil. In the soil, phytoliths are nonmobile. When phytolith analysis is applied to reconstruct the vegetation, the phytolith spectrum reflects the phytocoenosis that has formed it relatively accurately.

The territory of the southern part of western Siberia is characterized by complex terrain and a variety of climatic conditions. Due to these factors, all possible types of plant communities, ranging from spruce forests to dry steppes, are represented in the vegetation cover. A wide variety of phytocoenoses is a characteristic feature of the mountains. In many communities, grasses and sedges dominate the herbaceous layer. Many phytoliths formed by these plants produce phytolith spectra. However, the area considered is characterized by both natural and anthropogenic transformations of vegetation cover, and this factor may complicate the interpretation of phytolith spectra obtained from fossil soils.

The most studied phytolith spectra are those of tropical forests, where diagnostic forms are spherical morphotypes with different ornamentations belonging to Chrysobalanaceae and other tree families (Strömberg 2004). The phytolith spectra of pine forests in North America differ from the spectra of open grass ecosystems by the presence of special conifer morphotypes – blocky with pores, in which pores may be present (Blinnikov et al. 2001). An ecological classification has been proposed for the western part of Russia (Golyeva 2001). According to this classification, certain forms of phytoliths encountered together are typical for a particular type of vegetation. For example, a total of long particles of various forms, rondels, plates, and lanceolates, are characteristic of the deciduous forest. Currently, in the south of western Siberia, work is underway to study the forms of phytoliths, and their frequency in grasses of various ecological-coenotic groups (Solomonova et al. 2015). Another important aspect is the study of the specificity of the individual phytocoenose phytolith spectra, determining their dependence on the ecological-botanical-geographical features of regions and natural areas. The expansion of the database on the phytolith spectra of the phytocoenoses characteristic of the western Siberia south increases the precision of the reconstruction of the vegetation cover within the scope of paleoecological and archaeological research in this area.

## Material and methods

The research goal is to identify the differences and diagnostic characteristics of the phytolith spectra of the steppe and forest phytocoenoses. Research objectives include collecting surface soil samples, compiling geobotanical descriptions and her-

barium collection, obtaining phytoliths from soil samples and vegetative matter, creating phytolith spectra, and analyzing the obtained results.

The phytolith spectra of the soil and plant material surface samples have been studied in phytocoenoses in the south of western Siberia.

An oat grass-thoroughwax-sedge petrophytous meadow steppe represents the steppe communities (the Tigirek Ridge, Altai Krai, 747 m above sea level, southern slope; dominants: *Helictotrichon schellianum* (Hack.) Kitag., 1892, *Bupleurum multinerve* DC., 1826, *Carex pediformis* C.A. Mey., 1831), a true steppe of herb-sedge grass (the Kuminskiye Belki Ridge, the Altai Republic, 565 m above sea level, the slope of eastern exposure; dominants: *Carex pediformis* C.A. Mey., 1831, *Stipa capillata* L., 1762), alfalfa-wormwood-fescue steppe (Mikhailovsky district, Altai Krai, 6 km from the village of Ashchegul, 139 m above sea level; dominants: *Artemisia pontica* L., 1784, *Artemisia glauca* Pall. ex Willd., 1800, *Medicago falcata* L., 1753, Festuca valesiaca Gaudin, 1811), the true steppe of sedge-fescue-feather grass (Novoilyinka village, Khabarsky District, territory of the archaeological site Novoilyinka-3, 128 m above sea level; dominants: *Carex duriuscula* C.A. Mey., 1831, *Stipa pennata* L., 1753, *Festuca pseudovina* Hack. ex Wiesb., 1880) (Fig. 1).

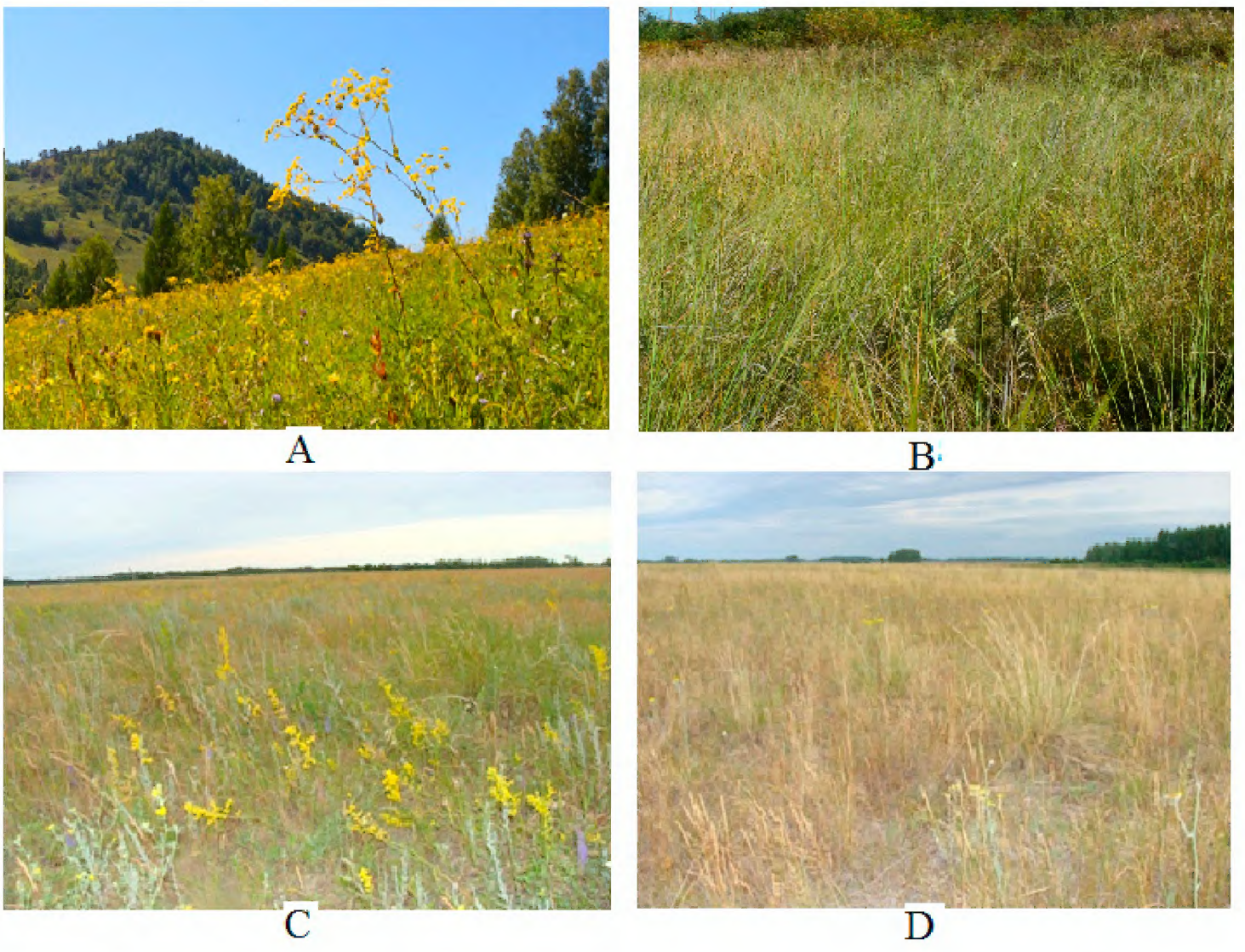


**Figure 1.** Photos of steppe communities: **A** – petrophytous meadow steppe of oat grass, deep wax, and sedge, **B** – true steppe of herb-sedge-feather grass, **C** – alfalfa steppe of wormwood-fescue, **D** – true steppe of sedge-fescue-feather grass.

Forest phytocoenoses encompass the following: wood sorrel-goutweed-ostrich fern pine forest (Iolgo Ridge, Altai Republic, 367 m above sea level; dominants: *Pinus sylvestris* L., 1753, *Betula pendula* Roth., 1788, *Carex macroura* Meinsh., 1901, *Pteridium aquilinum* (L.) Kuhn., 1879), undergrowth sedge-bracken pine forest (the Iolgo Ridge, the Altai Republic, 398 m above sea level; dominants: *Pinus sylvestris* L., 1753, *Betula pendula* Roth., 1788, *Matteuccia struthiopteris* (L.) Tod., 1866), forb-stone bramble-sedge pine forest (the Tigirek Ridge, Altai Krai, 806 m above sea level, south-eastern slope; dominants: *Pinus sylvestris* L., 1753, *Carex macroura* Meinsh., 1901, *Carex muricata* L., 1753), reed pine forest of stone bramble-sedge-wood (Baschelaksky Ridge, Altai Krai, 610 m above sea level, south-eastern slope; dominants: *Pinus sylvestris* L., 1753, *Carex macroura* Meinsh., 1901, *Calamagrostis arundinacea* (L.) Roth 1789) (Fig. 2).

The authors have taken samples from recent soils in triplicate. Phytoliths have been extracted from the soil by the maceration method and plants by the dry ashing method (Golyeva 2001). The authors have examined the samples using the Olympus BX-51 light microscope and CellSensStandard software. The phytolith sample for each sample has been at least 500 specimens. The phytolith spectra are plotted in the C2 software package. The phytolith ratio is provided as a percentage. The phytolith morphotypes are named according to the international phytolith nomenclature.

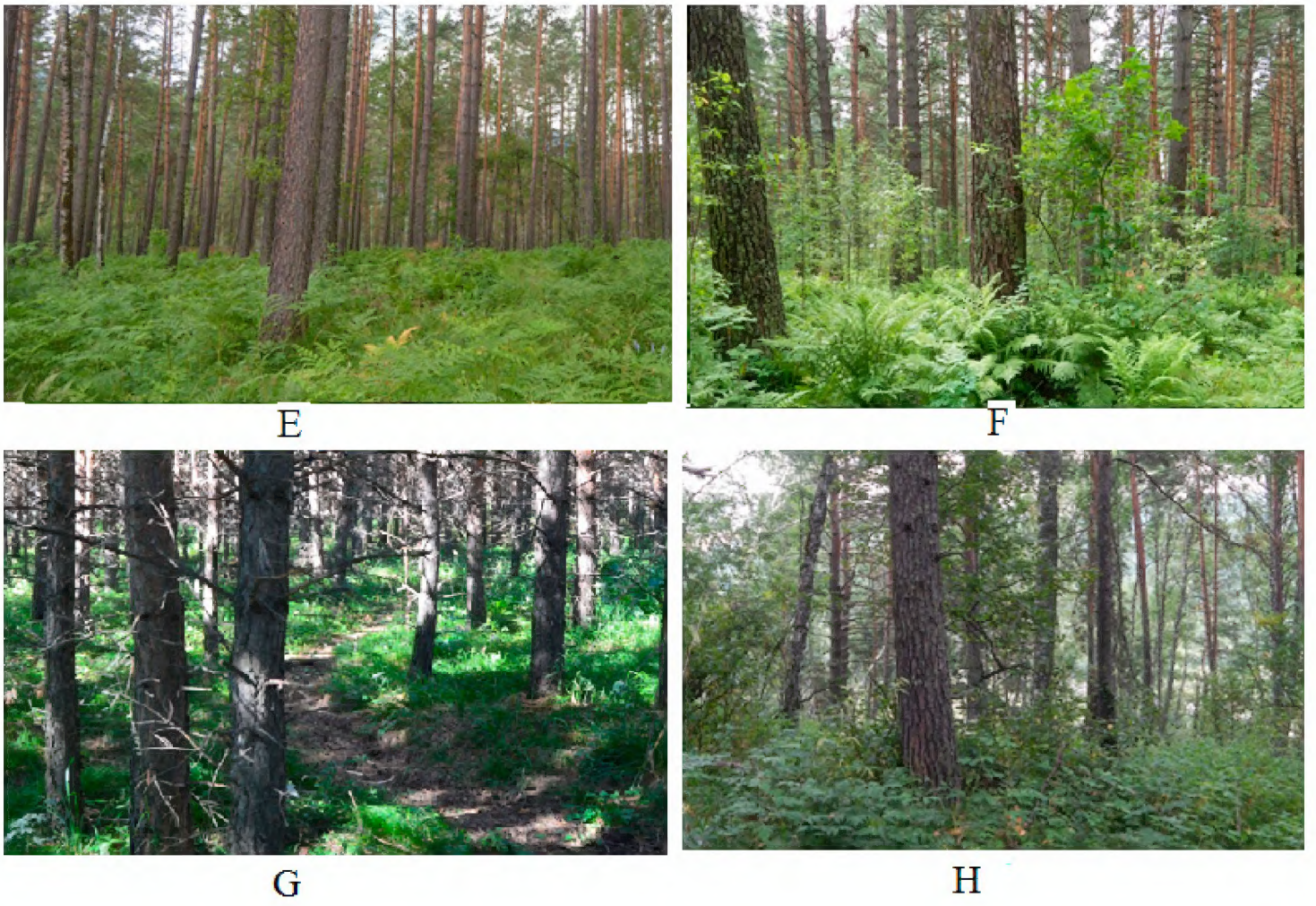


**Figure 2.** Photos of forest communities: **E** – wood sorrel-goutweed-ostrich fern pine forest, **F** – undergrowth-sedge-bracken pine forest, **G** – forb-stone bramble-sedge pine forest, **H** – stone bramble-sedge-wood reed pine forest.

## Results

Figure 3 illustrates the phytolith spectra of the steppe communities. The participation of individual community types in the formation of each spectrum is described below.

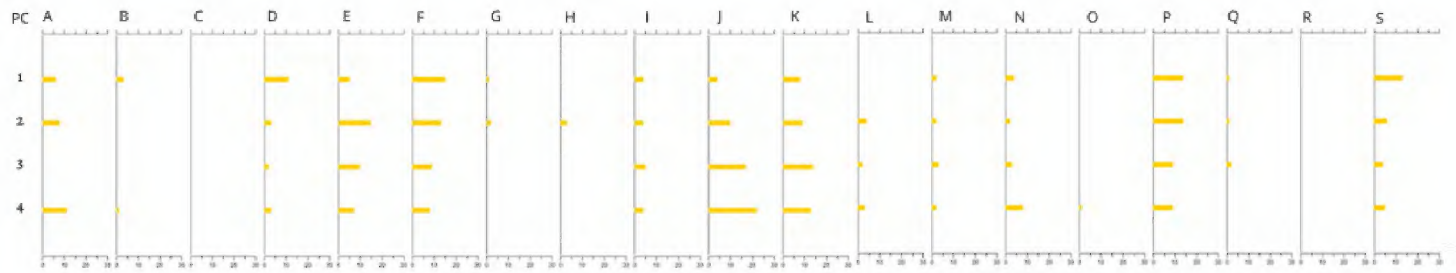


**Figure 3.** Distribution of phytolith morphotypes in steppe communities: **1** – herb-sedge-feather grass true steppe, **2** – sedge-fescue-feather grass true steppe, **3** – alfalfa-wormwood-fescue steppe, **4** – petrophytous meadow steppe of oat grass, **A** – polylobate trapeziforms, **B** – true bilobates, **C** – cross (symmetrical quadrilobate), **D** – trapeziform bilobate ("Stipa-type"), **E** – low trapezoid (pyramidal) rondel, **F** – conical rondel, **G** - single keeled rondel, **H** – multiple keeled rondels, **I** – lanceolates (trichomes), **J** – symmetrical psilate, **K** – psilate ribbed, **L** – perforated, **M** – strongly indented, **N** – psilate waly, **O** – three-angled, **P** – plates, **Q** – globular irregular, **R** – irregular dentate, **S** – other phytolith forms. Source: Compiled by the authors.

In the true steppe of herb-sedge-feather grass, trapeziform bilobate ('Stipa-type') and low conical rondel prevail. Polylobate trapeziforms, ribbed particles of psilate, and plates of irregular shape are represented to a lesser extent. The most significant contribution to the formation of the phytolith spectrum is made by the dominant *Stipa capillata* L., 1762. species. The diagnostic forms characteristic of the *Carex* L. genus (*C. pediformis* C.A. Mey., 1831) – the conical of Carex particles – are scarce. This morphotype is poorly preserved in the soil.

The sedge-fescue-feather grass true steppe is characterized by the predominance of conical and low trapezoid (pyramidal) rondels in the phytolith spectrum, which the presence of *Stipa pennata* L. can explain, 1753 in the community and the coenoforming role of the *Festuca* L. genus. Among the long particles, symmetrical psilate and ribbed particles dominate, lanceolates are less represented, and plates appear occasionally.

The spectrum of the alfalfa-wormwood-fescue steppe features typical meadow forms (lanceolates and polylobate trapeziforms). Conical and low trapezoid (pyramidal) rondels dominate. The substantial number of trapeziforms is associated with the dominant role of the *Festuca* L. genus. Expectedly, there are few short bilobates, since the community does not include the genera producing them, *Stipa* L., *Panicum* L. Psilate symmetrical, ribbed, and perforated rods dominate among the long particles.

The phytolith spectrum of the petrophytous meadow steppe of oat grass-thoroughwax-sedge is dominated by symmetrical psilate particles formed by *Fragaria Viridis* (Duchesne) Weston, 1766. The morphotypes of the dominant species are poorly represented.

Figure 4 shows the phytolith spectra of the forest communities.

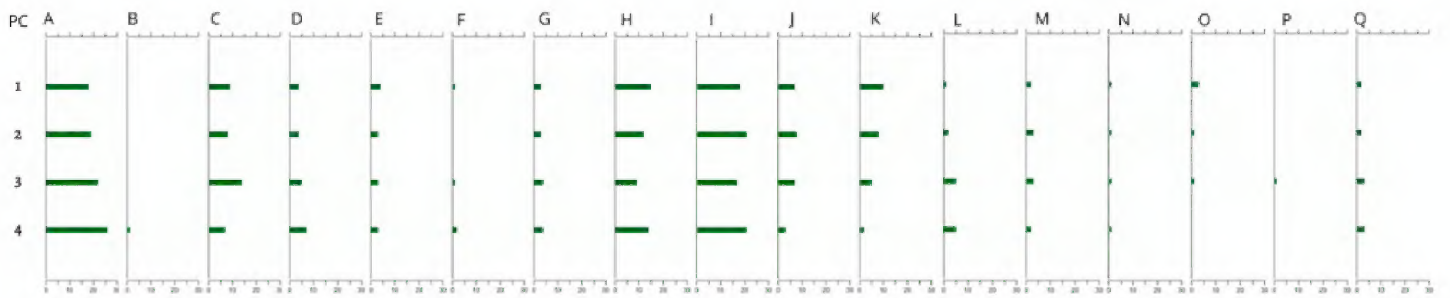


**Figure 4.** Distribution of the phytolith morphotypes in forest communities: **1** – wood sorrel-goutweed-ostrich fern pine forest, **2** – undergrowth-sedge-bracken pine forest, **3** – forb-stone bramble-sedge pine forest, **4** – stone bramble-sedge-wood reed pine forest, **A** – polylobate trapeziforms, **B** – true bilobates, **C** – trapeziform bilobate ("Stipa-type"), **D** – low trapezoid (pyramidal) rondel, **E** – conical rondel, **F** – single-keeled rondel, **G** - multiple keeled rondels, **H** – lanceolates (trichomes), **I** – psilate symmetrical, **J** – psilate ribbed, **K** – perforated, **L** – strongly indented, **M** – psilate waly, **N** – three-angled, **O** – plates, **P** – globular irregular, **Q** – other forms of phytoliths. Source: Compiled by the authors.

The wood sorrel, gingoutweed, and ostrich fern pine forest are characterized by the predominance of symmetrical psilate particles and polylobate trapeziforms. Lanceolates, perforated particles and trapeziform bilobate particles ('Stipa-type') are less represented. A significant number of symmetrical psilate particles is due to *Fragaria vesca* L., 1753 in this phytocoenosis.

Symmetrical polylobate particles and trapeziform polylobates dominate the phytolith spectrum of the undergrowth sedge-bracken pine forest. Lanceolates, trapeziform bilobate particles ("Stipa-type"), and ribbed and perforated psilate particles are found in smaller amounts (Fig. 5).

The forb-stone bramble-sedge pine forest is characterized by the predominance of polylobate trapeziforms, which is associated with the presence of such genera as *Calamagrostis* Adans., *Brachypodium* P. Beauv. and *Agrostis* L. in the community. Psilate symmetrical particles formed by dicotyledon plants also dominate the community.

In the spectrum of the stone bramble-sedge-wood reed pine forest, one can observe the predominance of polylobate trapeziforms and psilate symmetrical particles followed by lanceolates and then by low trapezoid (pyramidal) rondel formed by *Calamagrostis arundinacea* (L.) Roth., 1789. A small number of multiple keeled rondels are formed in the presence of *Elymus caninus* (L.) L., 1755.

The phytolith spectra of the steppes contain from 12 to 18 forms of phytoliths. The most diverse community in terms of phytolith composition is the alfalfa-wormwood-fescue steppe. The minor variety of phytoliths is characteristic of the

petrophytous steppe of oat grass-thoroughwax-sedge. Common dominants for all steppe phytolith spectra are low trapezoid (pyramidal) rondels and l psilate ribbed particles.

The herb-sedge-feather grass steppe is dominated by such morphotypes that are not abundant in any other phytocoenosis (trapeziform bilobate particles ['Stipa-type'] and irregularly shaped plates).

The phytolith spectra of the plain steppe communities (alfalfa-wormwood-fescue and sedge-fescue-feather grass steppe) are very similar in the phytolith composition (symmetrical and ribbed particles of the psilate, low trapezoid [pyramidal] rondels). The spectra of the mountain steppe phytocoenoses (the true herb-sedge-feather grass steppe and the petrophytous meadow steppe of oat grass-thoroughwax-sedge) are characterized by a weak similarity of morphotypes (low trapezoid [pyramidal] rondels and psilate ribbed particles).

The spectra of the forest communities possess a smaller phytolith diversity than those of the steppe. The common dominant morphotypes are polylobate trapeziforms, symmetric psilate particles, and lanceolates. These particles are generally characteristic of mesophytic communities (Speranskaya et al. 2013).

All considered forest communities are mountain forests with *Pinus sylvestris* L., 1753 as a coenosis-forming species. However, the characteristic of the particles of coniferous plants are not found in the soil spectra or are occasional.

There is a significant similarity in the spectra of all forest communities for 9 out of 15 morphotypes. The only difference is the stone bramble-sedge-wood reed pine forest. It implies the predominance of strongly indented particles over other forms of long particles.

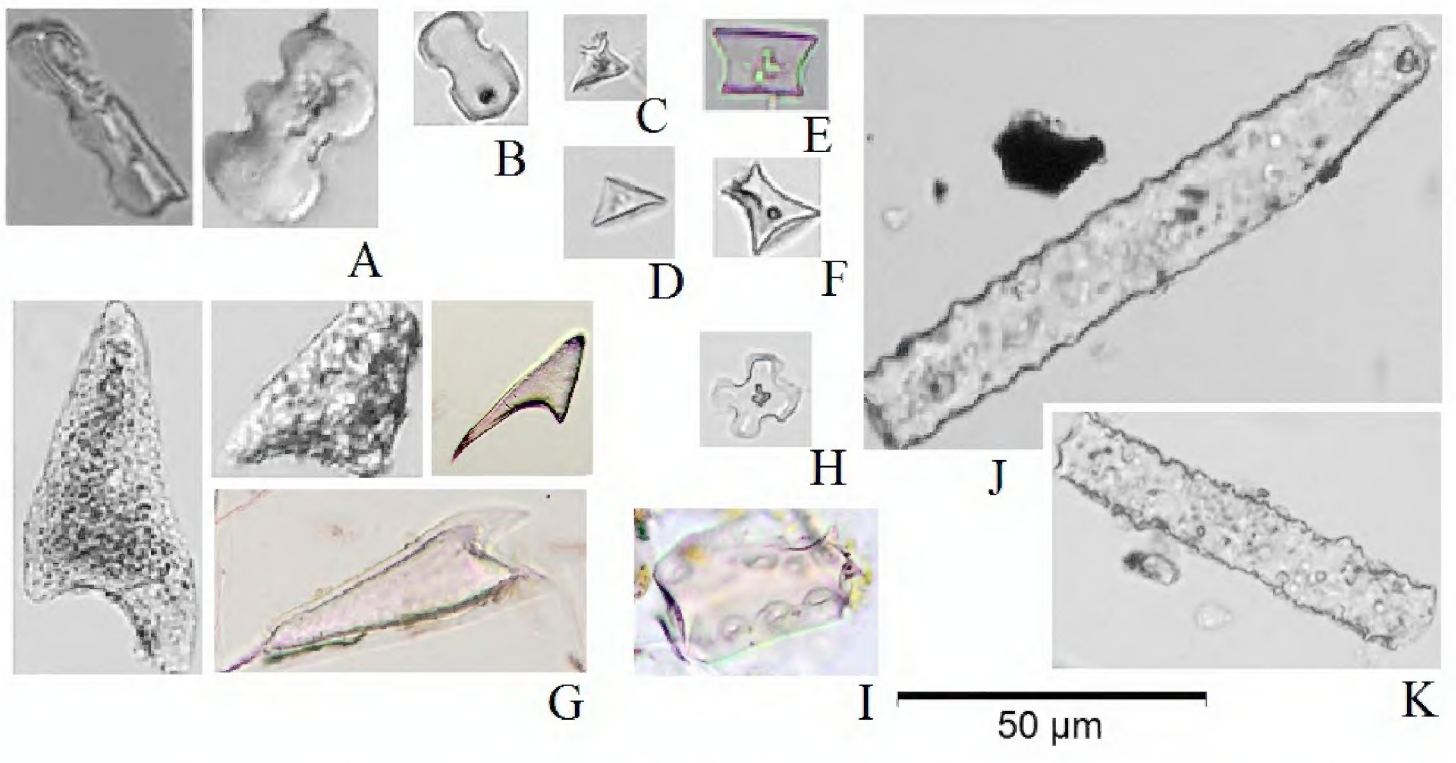


**Figure 5.** Microphotographs of morphotypes: **A** – polylobate trapeziforms, **B** – trapeziform bilobate ("Stipa type"), **C** – multiple keeled rondels, **D** – conical rondel; **E** – low trapezoid (pyramidal) rondel, **F** – single-keeled rondel, **G** – lanceolates (trichomes), **H** – cross (symmetric quadrilobate), **I** – phytolith with conifer pits, **J** – strongly indented, **K** – perforated. Source: Compiled by the authors.

## Discussion

Comparing the obtained phytolith spectra with previously published results confirms the diagnostic role of the low trapezoid (pyramidal) and conical rondels in steppe phytocoenoses (Silantyeva et al. 2018). The presence of trapeziform bilobate particles ("Stipa-type") in the spectrum is not always associated with the dominance of species of the genus Stipa in the community. This factor confirms the preceding data of the authors (Solomonova et al. 2015).

Lanceolates (trichomes) are essential for all types of communities. An increase in the proportion of lanceolates corresponds to an increase in mesophilic (Golyeva 2001). The authors confirm this dependence by giving an example of the spectra of both steppe and forest phytocoenoses. Chinese researchers mention that sedge phytoliths may dominate in the spectra of mountain forests (Li et al. 2018). The coniferous forests of North America are dominated by the phytoliths of coniferous species (Blinnikov et al. 2001). A minimum number of these particles characterizes the spectra studied.

## Conclusion

Research reveals the differences between steppe and forest phytocoenoses in phytolith spectra. The diagnostic forms of the steppe phytocoenoses are low trapezoid (pyramidal) rondels, conical rondels, and psilate-ribbed particles. The diagnostic forms of forest phytocoenoses are polylobate trapeziforms, symmetric psilate particles, and lanceolates.

The phytolith spectra obtained from the steppe communities can be used as models for reconstructing vegetation in the south of western Siberia. The spectra of forest phytocoenoses are weakly distinctive and can serve as models for an entire group of mountain pine forests.

The issue of accumulating coniferous plant phytoliths in recent soils requires further research.

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